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Application of Taguchi Technique in Gas Cutting Process - A Case Study

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ABSTRACT: This paper offers a different view of quality that has traditionally been used. Uniformity of products is of greater concern than just conformance to specifications. Improvement in quality by reducing the number of defectives is a goal every organization likes to pursue. However, the reduction of defectives requires an additional investment in procuring suitable technology and training of employees. Small scale industries with their resource crunch are at disadvantage because of this. Taguchi is a simplified way to overcome this problem. This work includes a detailed description of taguchi methodology. The statistical tool for the analysis of the analysis of the data (ANOVA) and the concept of orthogonal array are also dealt with. An attempt has been made to implement the 16-step methodology of taguchi in gas cutting. The results and verification of those results using Qualitek-4 software are also presented.

Keywords: Taguchi, Orthogonal array, Brinnel hardness number, ANOVA

Introduction: Quality has been defined by many as “being with specification”, “zero defects” or “customer satisfaction”. However, these definitions do not offer a method of obtaining quality or a means of relating quality to cost. For a long time manufacturing industries have worked from the basis of tolerance, which tends to suggest that the manufactured item would be passed as a acceptable if its quality lies within the specified range. This is popularly known as goal post philosophy. What are missing from this philosophy are the customer requirements. Product may meet the print specification, but if print does not meet customer’s requirements, then the true quality cannot be present. Hence, quality can be considered as delivering products and the services that met customer’s requirements and reach their expectations and standards.

Traditionally, quality has been assured by statistical process control. It is an online quality control, which achieve quality by reacting to deviations in the quality of the product recently produced by the plant. However, there is another approach for assuring quality known as Taguchi method, which relates to cost, not just to the manufacturer at the time of production, but to the customer and the society as a whole.

Taguchi defines quality in negative manner as “*the loss imparted to the society from the time the product is shipped.”*The loss is associated with the loses due to rework, waste of resources during manufacture, customer complaints and dissatisfaction and also eventual loss of market share. The principal of taguchi concept is that when designing a product it should be designed with minimum loss, with the relative product being closer to the optimum. Improving quality here connotes reducing variability in the functional performance of product’s quality characteristic so, statistically designed experiments are used to identify different sources of variation due to external disturbances thus effecting the products performance variation.

The main points of taguchi philosophy are:

1. Change the timing of application of quality control from online to offline, so that you can cease to rely on inspection i.e., “do it right the first time”.
2. Change experimental procedures from varying one factor at a time to varying many factors at a time through statistical experimental design techniques
3. Change objectives of experiments i.e., “achieving conformance to specification” to “achieving target and minimizing variability”.
4. Remove bad effect of cause not the cause of bad effect by appropriately tuning controllable factors.

In current experimentation of gas cutting, high pressure oxygen is directed against a plate. The oxygen jet burns the metal and blows it away causing the cut.

The experiments was carried out on a 16mm thick Sailma350 (0.23%C, 1.5%Mn, 0.055%S&P, 0.35% Si) plate with initial hardness 132 BHN.

Experimentation:

Taguchi views design of product is a three-phase program.

1. System design

2. Parameter design
3. Tolerance design

In **system design** phase, the design engineer uses a practical experience and engineering principles to create a functional design. Tooling requirements, production constraints related to capacity are investigated and all other issues related to the creation and production of feasible design are dealt with.

Parameter design involves determining influential parameters and their settings. The parameters that have linear relationship with the mean response are also identified.

Tolerance design is to determine tolerances or permissible ranges of parameters and factor settings that are identified in parameter design.

The parameter design phase is emphasized in the Taguchi approach. Although many companies spend more than 60% of their design activity on the system design, they ignore parameter design. System design may not come up with multitude of designs, but it does not test for sensitivity of the desired output to the input factors in order to come up with a cost effective design.

In parameter design, extensive empirical investigation is conducted to systematically identify the best settings of

(a) Process parameters that would produce that meets the customer's performance requirement (b) product's design parameters such that product's performance will be robust while the product is in actual field use.

Parameter design strategy:

Class 1: factors which effect both variation and average
Class 2: factors which effect variation only
Class 3: factors which effect average only
Class 4: factors which effect nothing

Steps in experimentation:

Determining problem to solved: when gas cutting is performed on an edge. The hardness of the edge increases. The edge heat is cut will have a hardness that is different from the whole plate hardness resulting in the non-homogenity of the plate. This may become a problem in further machining. The problem identified is the increase in the hardness of the edge of the plate on which gas cutting is performed.

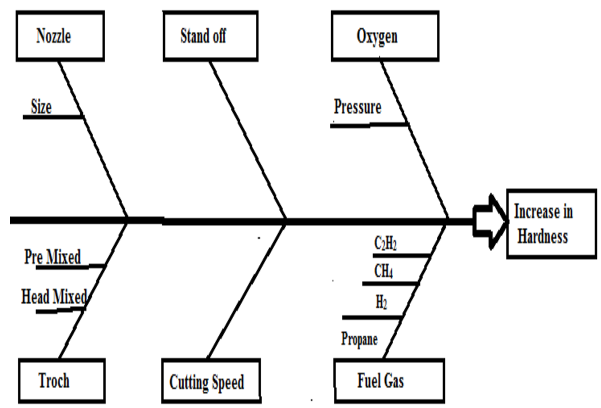
Objective of the experiment: A 10% to 30% increase in the hardness of the plate is observed. The objective is to minimize the increase in the hardness of the edge of the plate during gas cutting to a value of 151.5 BHN on an average. The hardness of the plate is determined by Rockwell's hardness tester and is converted to corresponding BHN.

Taguchi separates factors into two main group's *viz.,* control and noise factors.

Control factors are those which are set by the manufacturer and cannot be directly changed by the customer.

Noise factors are which the manufacturer has no direct control but which vary with the customer's environment and the usage.

Design of experiments: The factors which are expected to influence the performance are identified by cause-effect diagram



Out of various factors indicated in the cause-effect diagram oxygen pressure, fuel gas pressure and cutting speed are identified to be the control factors and the noise factors are neglected. The factors and their levels are shown in table 1.

Table 1

Factor	Process parameters	Level-1	Level-2
A	Oxygen Pressure	$2.11K_g/cm^2$	$2.81K_g/cm^2$
B	Acetylene Pressure	$0.34K_g/cm^2$	$0.51K_g/cm^2$
C	Cutting Speed	0.305m/min	0.381m/min

The synergistic effect of two or more factors in a factorial experiment is called interaction. The effect of one factor depends on another factor. A strategy may be to select the size of the experiment based only on factors and if there are any

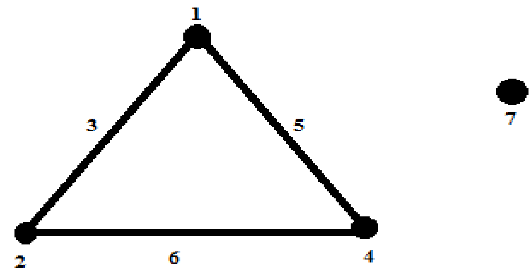
columns available afterward then assign these to an interaction of interest. The interaction between oxygen pressure and acetylene pressure, acetylene pressure and cutting speed, cutting speed and oxygen pressure are studied.

Factors	column no.							Hardness (BHN)	
Trial no.	1(**A**)	2(**B**)	3	4(**C**)	5	6	7	Trail: 1	Trail: 2
1	1	1	1	1	1	1	1	156	159
2	1	1	1	2	2	2	2	159	156
3	1	2	2	1	1	2	2	162	165
4	1	2	2	2	2	1	1	159	156
5	2	1	2	2	2	1	1	156	150
6	2	1	2	1	1	2	2	150	153
7	2	2	1	2	2	2	2	153	147
8	2	2	1	1	1	1	1	153	150

Design of experiments: design of experiments is widely used in determining the key variables influencing the quality characteristics of interest in the process. A designed experiment is a test or sequence of tests, in which purposeful changes are made to the output variables of a process, so that we may observe and identify corresponding changes. Taguchi design and orthogonal array are widely used in the design in manufacturing industries for process of optimization.

Orthogonality means that factors can be evaluated independently of one another; the effect of one factor does not bother the estimation of the another factor. The provision of orthogonality is balanced experimentation equal number of samples under the various treatment conditions.

Here L_8 orthogonal array design of experiment was adopted for experimentation. The linear graphs for L8 is as follows.



The factor 1 is assigned to column 1 and factor 2 to column 2 and factor 3 to column 4.The array along with factors assigned to columns is given in table 2.

Table: 2

ANOVA: Anova is a statistically based decision tool for detecting any difference in average performance of group of items tested. The decision rather than using pure judgment takes variation into account .ANOVA is mathematical technique which breaks total variation down into accountable sources. Total variation is decomposed into its appropriate components. Depending upon the number of decomposed components, ANOVA can be categorized as Noway, oneway, twoway and so on.

ASSUMPTIONS OF ANOVA:

1. The population from which the samples were obtained must be normally or approximately normally distributed.
2. Samples must be independent
3. Variance of populations must be equal

F-TEST:

There are many problems in which rather than estimate the value of a parameter, we must decide whether a statement concerning a parameter is true or false; that is we must test a hypothesis about a parameter. Statistically there is tool which provides a decision at some confidence level as to whether these estimates are significantly different. This tool is called an F-test, name after Sir Ronald Fisher.

$$F=S_1^2/S_2^2$$

When this ratio becomes large enough then the two sample variances are accepted as being un equal at some confidence level. To determine whether an F-ratio of two sample variances is statistically large enough 3 pieces of information are considered.

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1. The confidence level necessary
2. The dof associated with the sample variances in the numerator
3. The dof associated with the sample variances in the denominator

$F_{b:v1:v2}$ is the format of determining the explicit F value where b=risk; confidence=1-risk

V1= dof of numerator

V2= dof of denominator

The interpretation of ANOVA results fall into 2 categories.

1. Factors, which have an F-ratio exceeding some criterion
2. Factors, which have an F-ratio less than some criterion

The factors which have an F-ratio larger than the criterion are believed to influence the average value for the population and the factors which have an F-ratio less than criterion are believed to have no effect on the average.

Interpret the results:

Basing on the analyzed data the factors which are influential and not influential to the performance characteristics of interest is to be determined. The following are various interpretation methods.

- % contribution
- Estimating the mean
- Confidence interval around the estimated mean
- Observation method
- Ranking method
- Column effects method

Results and discussion:

Hardness values are obtained for 2 samples of each run are shown table 2.

The ANOVA is used to investigate the process parameters which significantly affect the performance characteristics. The F-test is used to analyze the significant effects of the parameters which form the quality characteristics.

ANOVA table is constructed

using the following formulae:

$$SS_{A=} \{ \sum_{i=1}^{k} (A^2_i/n_i)\}- T^2/N\ldots (1)$$

$$SS_{B=} \{ \sum_{i=1}^{k} (B^2_i/n_i)\}-T^2/N\ldots (2)$$

$$SS_{A*B}=[\sum_{i=1}^{k} (\sum_{j=1}^{k} (A*B)^2/n_{ij})]-T^2/N–(SS_A+SS_B)]\ldots(3)$$

$$SS_T=[\sum_{i=1}^{n} y_i^2]-T^2/N\ldots(4)$$

Total d.o.f = N-1

d.o.f of any factor =K-1

d.o.f of error=Total d.o.f- $\sum$ d.o.f of factors

V= (S)/(d.o.f)

$F=V/V_E$.... (5)

$P=SS/SS_T$…. (6)

Where $SS_A,SS_B,SS_C,SS_{A*B},S_{B*C},SS_{A*C},SS_{A*B*C}$ are the sum of the squares of factor-A, factor-B, factor-C and their interactions respectively.SS_T and SS_E are the sum of the squares of total and errors respectively. Where K is the number of levels.n_i is the number of trials for factor A,B,&C at the i^{th} level in the equations as shown above(similar calculations for SS_C and other interactions).A_i,B_i &C_i are sum of observations of factor A and factor B respectively.

V is the variance of the factor V_E is the variance of the error, d.o.f is the degrees of freedom is the % contribution is the test value that determines a decision at some confidence level as to whether these estimates are significantly different.

Col# / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 oxygen pressure	1	225	225	24.324	215.75	61.467
2 acetylene pressur	1	2.25	2.25	.243	0	0
3 INTER COLS 1 x 2	1	20.25	20.25	2.189	11	3.133
4 cutting speed	1	9	9	.972	0	0
5 INTER COLS 1 x 4	1	9	9	.972	0	0
6 INTER COLS 2 x 4	1	2.25	2.25	.243	0	0
Other/Error	9	83.25	9.25			35.4
Total:	15	351				100.00%

Anova table

Interpret the results:

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Out of the six various interpretation methods mentioned above, the following methods are used.

% contribution:

The expected sum of squares due to factor

$A = SS_A - (V_E)(V_A) = 225 - (9*1) = 216$

The % P of the contribution to the total variation can be calculate as

$P = \{(SS_A - (V_E)(V_A)\}/SS_T*100 = 61.53\%$

Estimating the mean:

$\mu = (150+153)/2 = 151.5$

Confidence interval:

$CI = \{ (F_{b:v1:v2})(V_E)/n_{eff}\}^{0.5} = 4.549$

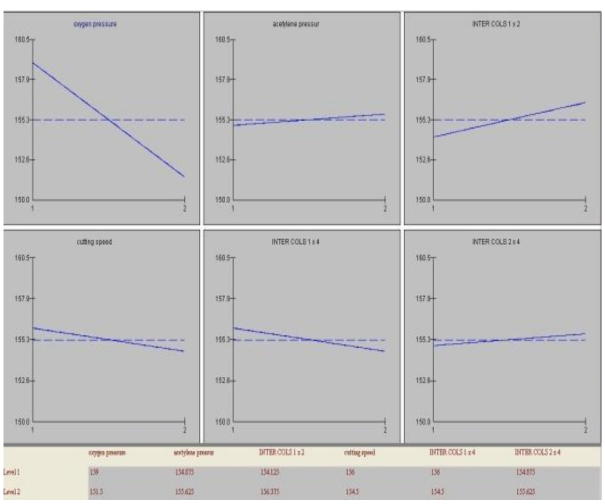
$\mu_{A2} = A_2 \pm CI = 151.5 \pm 4.549$

Therefore $146.952 \leq \mu_{A2} \leq 156.049$

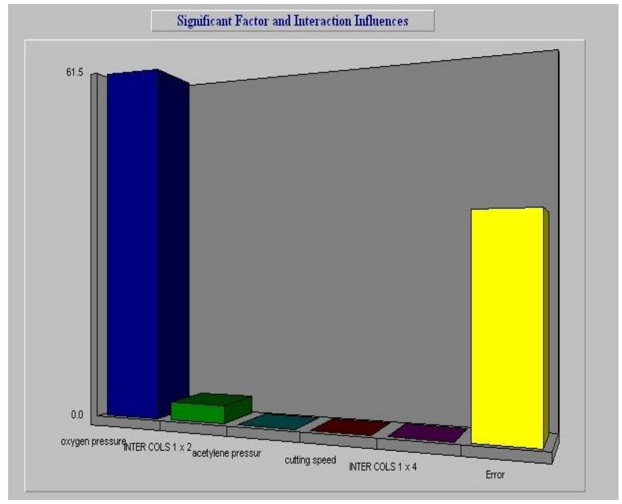
Select optimum levels of most influential control factors:

Factor A is found to be most influential. It is observed that hardness is minimum when A is set at level 2. Other factors are set at low cost level i.e., factor B is set at level1 and factor C at level 2

Multi plots



Bar graphs



Optimum conditions

Column # / Factor	Level Description	Level	Contribution
1 oxygen pressure	2.81 kg/cm2	2	-3.75
2 acetylene pressur	0.34 kg/c	1	-.375
3 INTER COLS 1 x 2	*INTER*	1	-1.125
4 cutting speed	0.381 m/min	2	-.75
5 INTER COLS 1 x 4	----------	2	-.75
6 INTER COLS 2 x 4	*INTER*	1	-.375

Total Contribution From All Factors........	-7.125
Current Grand Average Of Performance...	155.25
Expected Result At Optimum Condition...	148.125

Run a confirmation experiment:

Experiment is conducted thrice with optimum levels of factors. The average of three values observed as 149.83 BHN which is in the range of $146.952 \leq \mu_{A2} \leq 156.049$

Conclusion:

Taguchi techniques aim at obtaining and maintaining quality at lowest cost. They lead to excellence in selection and setting of design parameters and hence their application helps in reducing the defectives produced. In the case study out of the factors considered, oxygen pressure has great impact on the performance characteristics. When gas cutting is performed in sailma 350,16mm thick plate under normal conditions the hardness is found to be 155.25 BHN. While under optimal conditions the same is found to be 149.83 BHN. The results are confirmed using Qualitek-4.The results are valid only for the levels of the factors selected.

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